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A review on fuel economy test procedure for automobiles: Implementation possibilities in Malaysia and lessons for other countries

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ABSTRACT

Automobiles are considered as the main energy consumer in the transportation sector. According to the National Energy Balance, its accounted for about 36% of the total energy consumption in Malaysia. In order to reduce energy consumption in this sector, this country must consider setting fuel economy standards for motor vehicles sometime in near future. The first step toward developing fuel economy standards is to create a precise test and rating procedure for the automobiles. The test procedure is the technical foundation for all related programs namely; fuel economy standards, fuel economy labels and incentive programs. The test conditions should represent the driving situations and environment of the country. This paper is attempts to present a critical review on fuel economy testing procedure around the world and to propose a process for selecting a fuel economy test procedure for automobiles based on the conditions and requirements of the country. The internationally recognize test procedure adopted by several countries is also presented in this paper. Even though the paper only discusses the test procedure for automobiles, the methods can be directly applied for other types of vehicles and in other countries without major modifications.

Contents

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1. Introduction

In the past decade the global warming and air pollution facing by the world today are reached to a critical level. Therefore, in the past few years there has been a growing concern about energy use and its adverse impact on the environment all over the world [1–5]. The most promising strategy to tackle this problem is to implement renewable energy and energy efficiency policies that are already been used in many developed countries around the world. Some of the successful programs on renewable energy implementation are presented in Refs. [6–30], some of the successful programs on energy efficiency are also discussed in Refs. [26–48]. One of the most successful programs is by implementing the fuel economy standard and labeling [49–51]. In many countries, cars are tested for fuel economy through standard procedures before being authorized for sale [52–57]. The test simulates a range of driving conditions at highway speeds and at speeds more typical of urban driving. All tests are simulated on-road fuel consumption of the vehicles. The tests reflect the value of fuel economy of the car based on the driving conditions. Unfortunately, normally in the developing countries, vehicles are not tested for fuel economy, in these countries governments are one of the best authorities who can introduce that kind of tests because the program is quite sensitive and can significantly affect the automotive market. However, in the absence of national test procedures, consumer organizations can act as an authority to develop test procedures, conduct the testing and publishing results in the interests of their members [126].

Generally, the fuel economy testing for a new automobile is differed from country to country and from region to region. This is due to the extent that the typical driving condition changes by country and region in a number of respects that will affect fuel consumption. This includes prevailing urban versus extra highway driving patterns, ambient temperatures that determine the use of air conditioners or heater. At the same time, there is dissatisfaction with current test procedures everywhere; real fuel consumption on the real environment tends to be higher than the laboratory tests used to certify new vehicles. The discrepancy arises particularly in stop-go, urban driving conditions [126]. Some of the works related to the vehicle test procedure are discussed by Refs. [58–71].

2. Automobile energy balance

In the internal combustion engine, most of the energy obtained from the fuel is released as a waste to the environment. The chemical energy conversion is used to turn the wheels to provide acceleration, to overcome aerodynamic drag and rolling resistance, lastly only 12.6% of the total energy converted is used as useful work and the rest is lost to the environment. Therefore, there is a significant potential to improve fuel economy using advanced technologies. The energy balance for an automobile is presented in Fig. 1 [72].

Even the latest internal combustion engines convert only one-third of the potential chemical energy of the fuel into useful mechanical work. The rest of the energy is lost as waste heat, the friction of moving engine parts and pumping air into and out of the engine. All of these steps at which energy is wasted, provides new opportunities for advanced technologies to improve the efficiency of automobile. As a result, emerging of new technologies is observed in almost each year and more advanced technologies in the research stage become available in the next 10–15 years. A more complete discussion of these technical issues can be found in Refs. [73–96].

3. Fuel economy test procedure

The world forum for harmonization of vehicle regulations of the United Nation economic commission for Europe has brought governments and automobile manufacturers together to work on a new harmonized test procedure to be adopted. The result is expected to increased focus on urban driving conditions, at least in regions that have less emphasis on these conditions in current tests. However, it is expected that it may take many years to come with an agreement. In the meantime, there might be merit in establishing a world standard emission test as an additional and complementary standard test to provide purchasers with information on fuel economy or fuel consumption. A global fuel economy test procedure, could include test variants that cover different types of driving conditions, allowing countries to use a weighted average of the variants to best reflect their own conditions. Europe, Japan, and the United States are the countries that have developed their own unique test procedures to determine fuel economy and greenhouse gas (GHG) emissions for new motor vehicles [126]. Some of the test procedure in used in other countries can be found in Refs. [97–99].

Several essential steps should be taken to establish fuel economy standards and labels; the first step is to establish a precise test procedure. A test procedure is the foundation for fuel economy standards, fuel economy labels and other related programs. It provides the manufactures, regulatory authorities and consumers a method of consistently evaluating fuel use across different models. The second step is to set up fuel economy standards based on the vehicle fuel economy test data. Nowadays, many vehicles have been tested with at least one of the test procedures when they want to be sold in the market. The data proved during the test can be used to accelerate setting the new test standards. And the third step is to develop uniform fuel economy labels. Although, labels are very informative for the consumers, but they are not absolutely necessary for standards. The energy labels, can contribute to further potential savings of the standards. The last step is to develop some incentive programs as an option for standards and labels. The

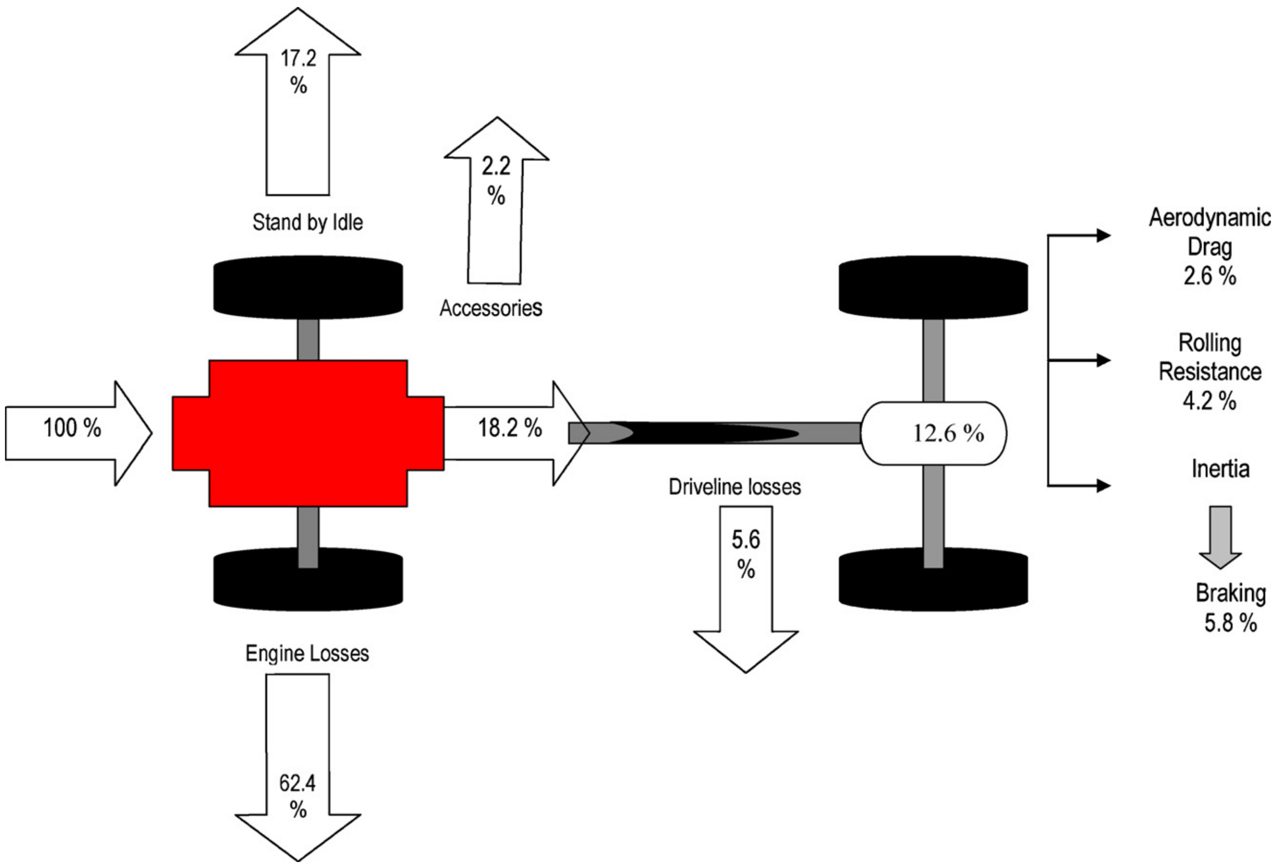

Fig. 1. Energy balance of an automobile.

hierarchy of fuel economy standards and labels proposed in this study are shown in Fig. 2.

The fuel economy is normally measured under the controlled condition using standard test procedure that is specified in the laboratory. Generally, manufacturers should send the test report of their prototype automobile to authority to review the results and confirm via their own recognized laboratory test. The test procedure normally consists of the following steps [100]:

Fig. 2. Hierarchy of test procedure, fuel economy standards, fuel economy labels and incentive programs.

(i) The vehicle's drive wheels are placed on a dynamometer to simulate the driving environment. The required energy to move the rollers can be adjusted to account for wind resistance and the vehicle's weight.
(ii) On the dynamometer, a professional driver or programmed robot drives the vehicle through a standard driving routine, or schedule, which simulates a virtual trip in a city or on a highway.
(iii) Each schedule specifies the vehicle speed of traveling during the test procedure.

The graphical test cell layout of a fuel economy test procedure is presented in Fig. 3. [101].

For vehicles using fossil fuels such as gasoline, diesel, natural gas, and, a hose is connected to the tailpipe to collect the exhaust gas during the test. The carbon in the exhaust is measured to calculate the amount of fuel burned during the test. This method is more accurate than using a fuel gauge. However, this procedure is not suitable for the vehicles that use non-fossil fuels, such as fuel cell vehicles and electric vehicles [100]. The fuel economy or fuel consumption calculation is presented in Table 1 [102].

4. Automobile test procedure in selected countries

The automobile test procedures in selected countries are mostly referred to references as presented in the following section and subsection. To avoid the misinterpretation about the test methods and its sequences, the procedures have quoted according to the data and the text presented in the references without any major changing or paraphrase. However, please refer to the original standard testing method for testing the vehicles.

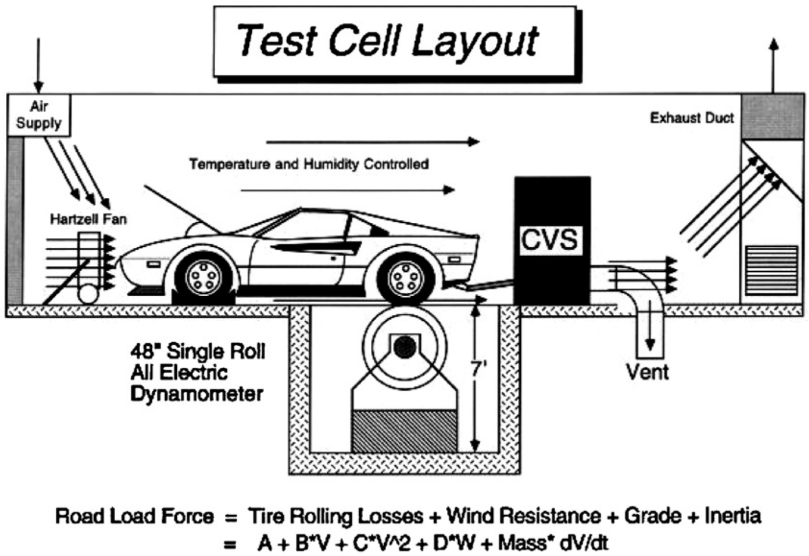

Fig. 3. Layout of fuel economy and emissions testing.

4.1. United States

There are many types of fuel economy and emission test procedure in United States, some of them are discussed below.

4.1.1. US EPA test procedure

In the US Corporate Average Fuel Economy (CAFÉ) test procedure, 55% weight is given to the city driving cycle and 45% is dedicated to the highway driving cycle for fuel economy testing. The EPA test procedure measures vehicles by running them on a series of driving cycles, or schedules, to specify the vehicle's speed specified points during the laboratory tests. Before the year 2007 only the city and highway cycles were conducted. From the Beginning of the year 2008, three additional tests were adopted to adjust the city and highway driving that include the higher speeds, the use of air conditioning and for the colder climate temperatures [103].

4.1.2. FTP (Federal Test Procedure)-72

The U.S. FTP-72 driving routine test is also called Urban Dynamometer Driving Schedule (UDDS) or LA-4 cycle. The same driving cycle is known in Sweden as the A10 or CVS (Constant Volume Sampler) cycle and in Australia as the ADR 27 (Australian Design Rules) cycle. This cycle should not be confused with the UDDS schedule for heavy-duty vehicles. The cycle simulates an urban driving for 12.07 km with frequent stops. The maximum speed of this test is 91.2 km/h (56.7 miles/h) and the average speed is 31.5 km/h (19.6 miles/h). The cycle pattern of FTP-72 is given in Fig. 4 [103].

Table 2
Cycle schedule for FTP-75.

Description	Value
Distance traveled	11.04 miles (17.77 km)
Duration	1874s
Average speed	21.2 mph (34.1 km/h)

The cycle consists of two phases; the first phase is for 505 s for the distance of 5.78 km at 41.2 km average speed and the second phase is for 864 s. The first phase begins with the cold start of the engine and the second phase starts after 10 min of stopping the engine. For this test procedure weighting factors of 0.43 and 0.57 are applied to the first and second phase, respectively [103].

4.1.3. Federal Test Procedure FTP-75

The FTP-75 has been used for emission investigation of the light-duty vehicles for an effective model year 2000 in the U.S. Vehicles have to be additionally tested on two Supplemental Federal Test Procedures (SFTP) designed to address shortcomings of the FTP-75 in the representation of (1) aggressive, high speed driving, and (2) the use of air conditioning [103].

4.1.3.1. City schedule. The FTP-75 cycle is derived from the FTP-72 cycle by adding a third phase of 505 s, identical to the first phase of FTP-72 but with a hot start. The third phase starts after the engine is stopped for 10 min. Thus, the entire FTP-75 cycle consists of the following segments [103,104]:

(i) Cold start phase

Table 1
Fuel economy or fuel consumption calculation.

Country	Fuel	Formula
USA	Diesel	$FE = \frac{K}{0.886\times HC+0.429\times CO+0.273\times CO_2}$ $K = 2778$
	Gasoline	$FE = \frac{5174\times 10^4\times CWF\times SG}{[(CWF\times HC)+(0.429\times CO)+(0.273\times CO_2)]\times[0.6\times SG\times NHV)+5471]}$
	$FE_{Determination}$	$FE = \frac{1}{0.55/CFE+0.45/HFE}$ [mpg] With CFE = FE from city test [mpg] HFE = FE from highway test [mpg]
Japan	Diesel/gasoline	$FE = \frac{K}{0.866\times HC+0.429\times CO+0.273\times CO_2}$ $\left[\frac{km}{l}\right]$ $K_{gasoline} = 734$ and $K_{diesel} = 640$
EU	Diesel/gasoline	$FE = \frac{0.866\times HC+0.429\times CO+0.273\times CO_2}{K}$ $\left[\frac{l}{100\,km}\right]$ $K_{diesel} = SG/0.1155$ and $K_{gasoline} = SG/0.1154$
	$FE_{Determination}$	$FE = \frac{1}{0.55/CFE+0.45/HFE}$ [mpg] CFE = FE from city test [mpg]; HFE = FE from highway test [mpg]

Note: CWF, carbon weight fraction ASTM D 3343 HC, CO, CO_2: g/km. SG, specific gravity of fuel ASTM D 1298 [g/km]. NHV, net heating value ASTM D 3338 US [Btu/lb] [102].

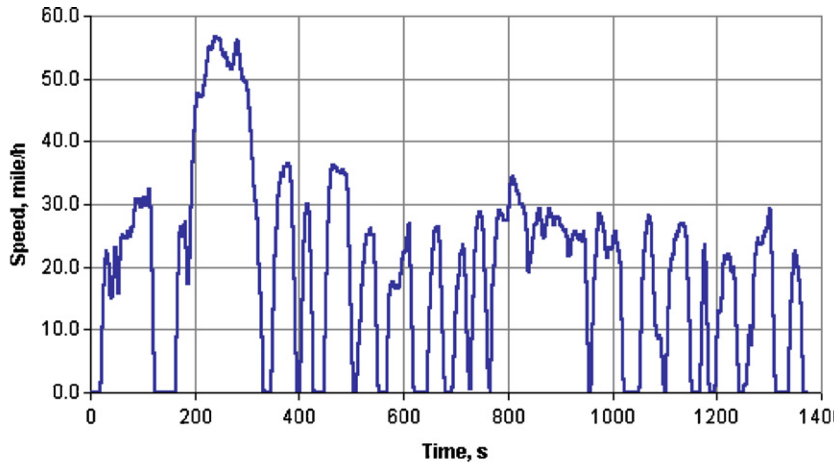

Fig. 4. FTP-72 cycle.

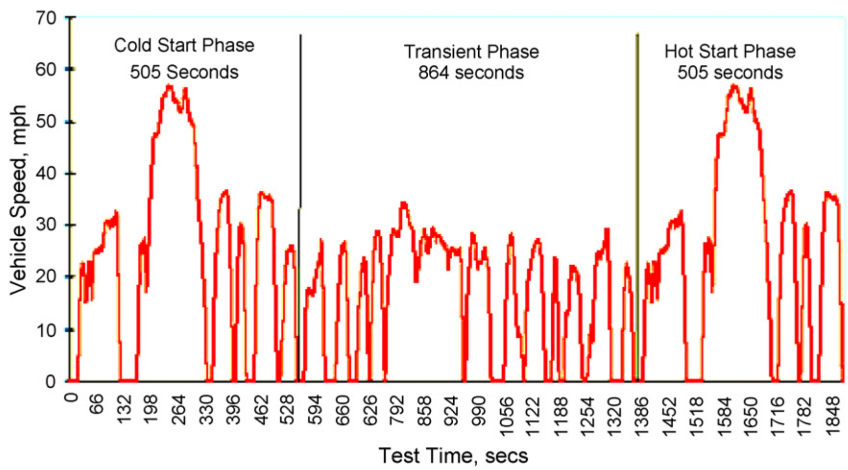

Fig. 5. FTP-75 cycle city driving.

(ii) Transient phase
(iii) Hot start phase.

The basic parameter of the cycle is presented in Table 2 and the cycle pattern is presented in Fig. 5 [103]:

The emission from each phase is then collected in a separate container, analyzed and presented in g/km (g/mile). The weighting factors are 0.43 for the cold start, 0.57 for the hot start phase and 1.0 for the transient phase. The FTP-75 cycle is known in Australia as the ADR 37 (Australian Design Rules) cycle [103].

4.1.3.2. Highway schedule. The highway fuel economy test (HWFET) cycle is a chassis dynamometer driving cycle test, proposed to determine the fuel economy of light-duty vehicles by the U.S. EPA. Some characteristic parameters of the cycle are given in Table 3 and the EPA highway fuel economy test pattern is also presented in Fig. 6 [103]:

4.1.3.3. Higher speed schedule. The US06 Supplemental Federal Test Procedure (SFTP) was developed to address the shortcomings of the FTP-75 test cycle due to aggressive, high speed and/or high acceleration driving behavior, rapid speed fluctuations and driving behavior following startup. The cycle is presented in Table 4 [103]. The SFTP US06 cycle for high speed pattern is presented in Fig. 7 [103].

4.1.3.4. Air conditioning schedule. The SC03 Supplemental Federal Test Procedure (SFTP) is introduced to represent the engine load and emissions associated with the use of the air conditioning system in vehicles certified over the FTP-75 test cycle. The cycle is presented in Table 5 [103] and the pattern of SFTPSC03 cycle with

Table 3
Highway fuel economy test.

Description	Value
Duration	765 s
Total distance	10.26 miles (16.45 km)
Average speed	48.3 miles/h (77.7 km/h)

Table 4
Higher speed schedule for FTP-75.

Description	Value
Duration	596 s
Total distance	12.8 km (8.01 km)
Average speed	77.9 km/h (48.4 miles/h)
Maximum speed	129.2 km/h (80.3 miles/h)

Table 5
Air conditioning schedule.

Description	Value
Duration	596 s
Total distance	5.8 km (3.6 miles)
Average speed	34.8 km/h (21.6 miles/h)
Max speed	88.2 km/h (54.8 miles/h)

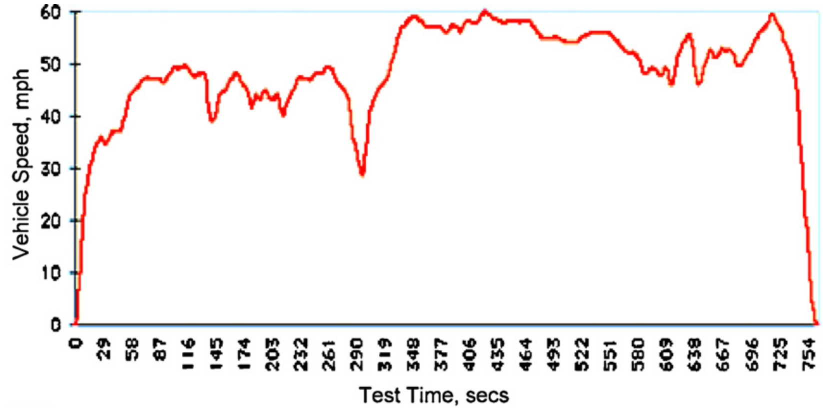

Fig. 6. EPA highway fuel economy cycle.

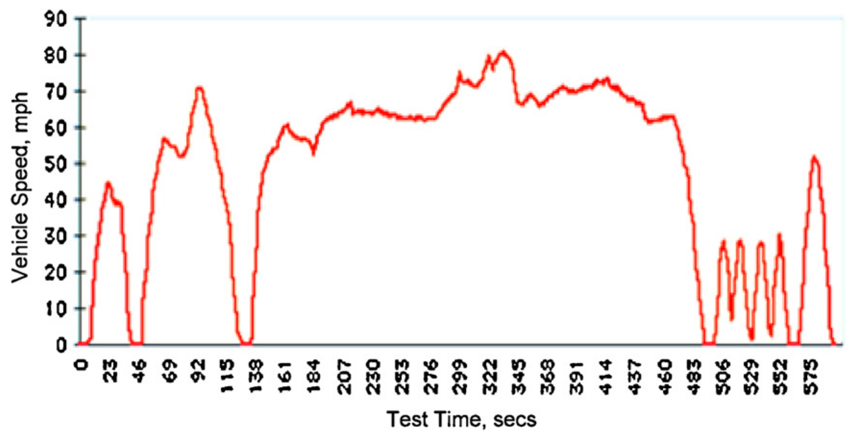

Fig. 7. SFTP US06 cycle for high speed.

air conditioner is shown in Fig. 8 and FTP colder temperature cycle for cold temperature pattern is given in Fig. 9 [103].

The comparison of US CAFÉ based on driving schedule is tabulated in Table 6 [103].

4.1.4. Other EPA test use in US for specific region

4.1.4.1. California testing procedure. The California Unified Cycle (UC) is a dynamometer testing cycle for light-duty vehicles proposed by the California air resources board. This test is also referred to as the UCDS. One of the applications of the UC cycle is testing the vehicles fitted with direct ozone reduction technologies, the SFTP was used for that purpose earlier. The UC test has a similar three-bag structure, but is a more aggressive driving cycle than the FTP-75. It has higher speed, higher acceleration, fewer stops per mile and less idle time. Bags 1 and 2 are run consecutively in the UC test, followed by a 10 min hot soak, and then followed by Bag 3 which is a duplicate of Bag 1. Overall cycle emissions are calculated in the same manner as the weighted, overall FTP-75 formula, taking actual mileage from the UC into account. Some of the characteristic parameters of the cycle are presented in Table 7 and the pattern of California unified cycle is shown in Fig. 10 [103].

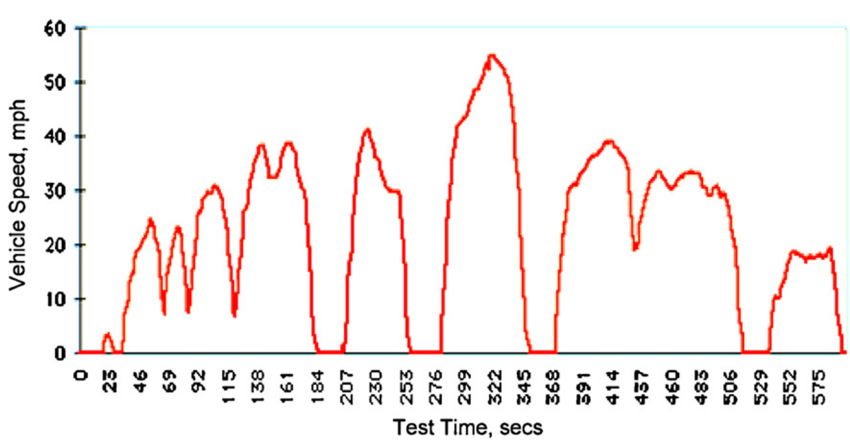

Fig. 8. SFTP SC03 cycle with air conditioning.

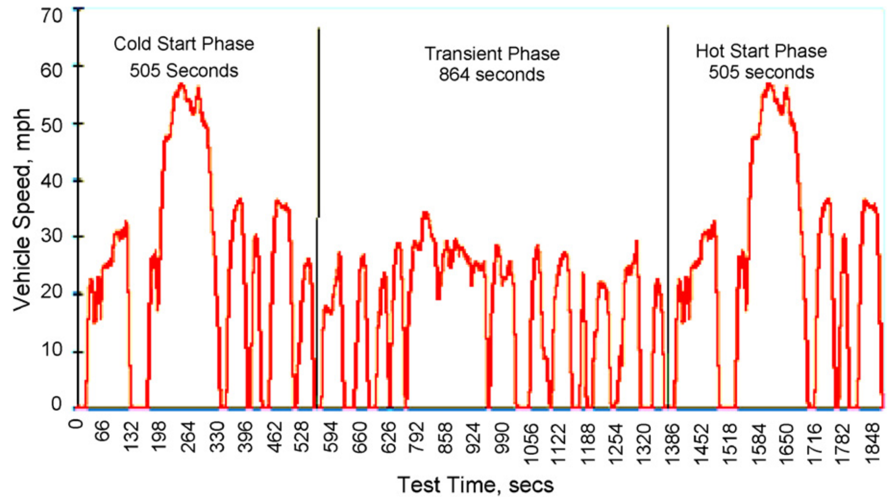

Fig. 9. FTP-75 colder temp cycle for cold temperature.

Table 6
Comparison of test procedure based on driving schedule.

Driving schedule attributes	Test schedule				
	City	Highway	High speed	AC	Cold temp
Trip type	Low speeds in stop-and-go urban traffic	Free-flow traffic at highway speeds	Higher speeds; harder acceleration and braking	AC use under hot ambient conditions	City test w/colder outside temperature
Top speed	56 mph	60 mph	80 mph	54.8 mph	56 mph
Average speed	21.2 mph	48.3 mph	48.4 mph	21.2 mph	21.2mph
Max. acceleration	3.3 mph/s	3.2 mph/s	8.46 mph/s	5.1 mph/s	3.3 mph/s
Simulated distance	11 miles	10.3 miles	8 miles	3.6 miles	11 miles
Time	31.2 min	12.75 min	9.9 min	9.9 min	31.2 min
Stops	23	None	4	5	23
Idling time	18% of time	None	7% of time	19% of time	18% of time
Engine startup[a]	Cold	Warm	Warm	Warm	Cold
Lab temperature	68–86 °F	95 °F	20 °F		
Vehicle air conditioning	Off	Off	Off	On	Off

[a] A vehicle's engine does not reach maximum fuel efficiency until it is warm.

Table 7
California testing procedure.

Description	Unified cycle	Bag 1	Bag 2
Duration	1435 s	300 s	1135 s
Total distance	9.8 miles (15.7 km)	1.2 miles (1.9 km)	8.6 miles (13.8 km)
Average speed	24.6 miles/h (39.6 km/h)	–	–

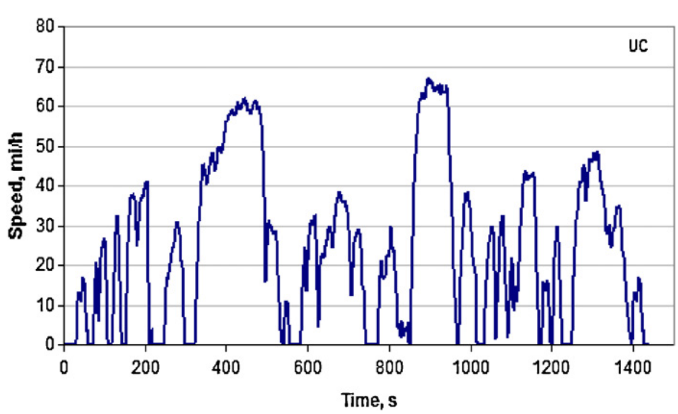

Fig. 10. California unified cycle.

4.1.4.2. New York testing procedure. The EPA New York City Cycle (NYCC) test was developed for chassis dynamometer testing cycle for light-duty vehicles. The test simulates the low speed urban driving with frequent stops. The basic parameters of the cycle are presented in Table 8 and the pattern of EPA New York City cycle is shown in Fig. 11 [103].

4.1.4.3. Standard road testing procedure. The Standard Road Cycle (SRC) and Standard Bench Cycle (SBC) were introduced by the U.S. EPA in the year 2005 for predicting the emissions of new

Table 8
New York testing procedure.

Description	Value
Duration	598 s
Total distance	1.89 km (1.18 miles)
Average speed	11.4 km/h (7.1 miles/h)
Maximum speed	44.6 km/h (27.7 miles/h)

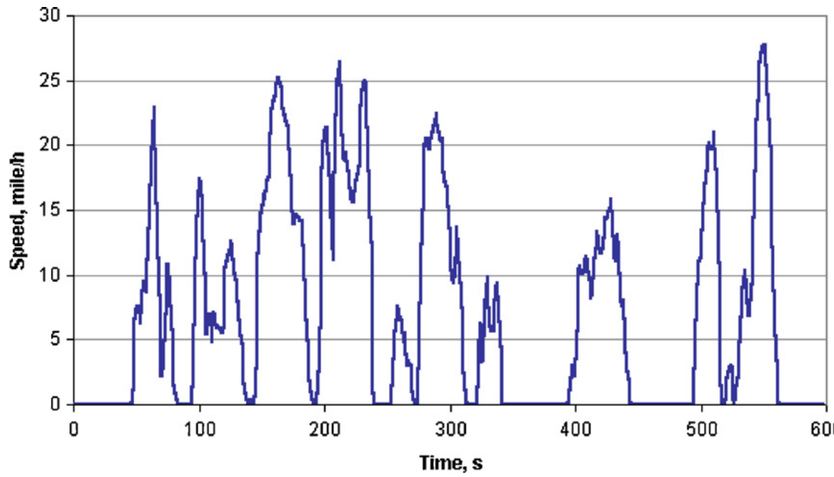

Fig. 11. EPA NYCC cycle.

light-duty vehicles under the Compliance Assurance Program 2000 (CAP 2000). The CAP 2000 durability provisions and the SRC/SBC tests are applicable mostly to gasoline cars with three-way catalysts [103].

4.2. European testing procedure (NEDC)

The New European Driving Cycle (NEDC) is used for certification of light-duty vehicles in European countries. The Urban Driving Cycles (ECE) + Extra Urban Driving Cycle (EUDC) test is conducted on a chassis dynamometer. The cycle also known as the Motor Vehicle Exhaust Gas-A (MVEG-A) cycle, which is used for emission certification of the light-duty vehicles in European countries. The entire cycle includes four ECE segments, as presented by Fig. 12, repeated without interruption, followed by one EUDC test segment, as given in Fig. 13 [103]. Before the test, the car is allowed to soak for at least 6 h in a test temperature of 20–30 °C. The car then started and allowed to idle for 40 s. However, for the effective year of 2000, that idling period has been eliminated, i.e. engine starts at 0 s and the emission sample collecting begins at the same time. This modified cold-start procedure is also referred to as the New European Driving Cycle (NEDC). Emission data are collected during the cycle according to the constant volume sampling technique, analyzed and presented in g/km for each of the pollutants [103].

The ECE cycle is an urban driving cycle, also known as UDC. It was devised to represent city driving conditions, e.g. in Paris or Rome. It is characterized by low vehicle speed, low engine load and low exhaust gas temperature [103,105]. The above urban driving cycle represents Type I test, as defined by the original ECE 15 emission procedure. Type II test is a warmed-up idle tailpipe CO test conducted immediately after the fourth cycle of the Type I. Type III test is a two-mode (idle and 50 km/h) chassis dynamometer procedure for crankcase emission determination. The EUDC (Extra Urban Driving Cycle) test cycle is given in Fig. 13 [103].

The EUDC segment was added after the fourth ECE cycle to account for more aggressive and high speed driving modes. The maximum speed of the EUDC cycle is 120 km/h [103,106]. An alternative EUDC cycle for low-powered vehicles was also defined with a maximum speed limited to 90 km/h as presented in Fig. 14 [103].

However, the current type approval cycle may not be able to accurately assess vehicle's emission and fuel consumption due to its inadequate representation of real-world driving [107,108]. There is a strong agreement that driving characteristics of each city and country are unique due to different fleet composition, driving behavior, public transportation system and road network topography [109,110]. Due to this problem, some of the European countries develop new testing procedure especially for the urban area in the country.

4.2.1. Athens testing procedure/Greece

Athens develops their own unique test procedure to get more asses vehicle emission and fuel consumption as NEDC is inadequate to represent of real-world driving in Athens. The Athens Driving Cycle (ADC) is a more realistic cycle based on the real-world

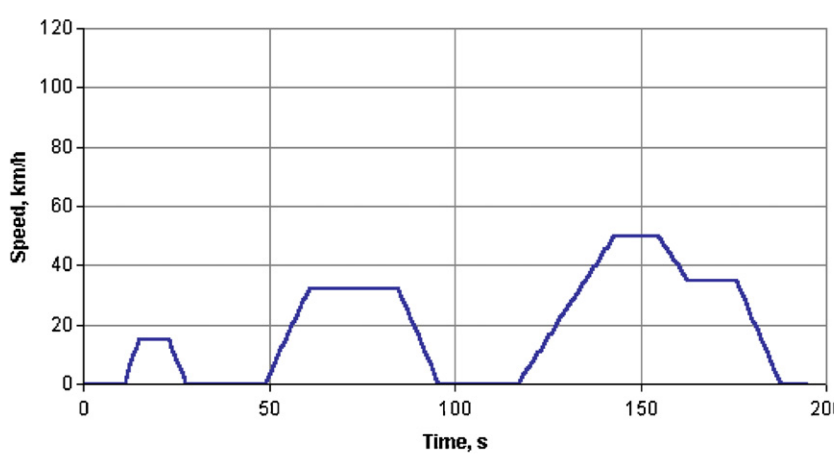

Fig. 12. ECE 15 cycle.

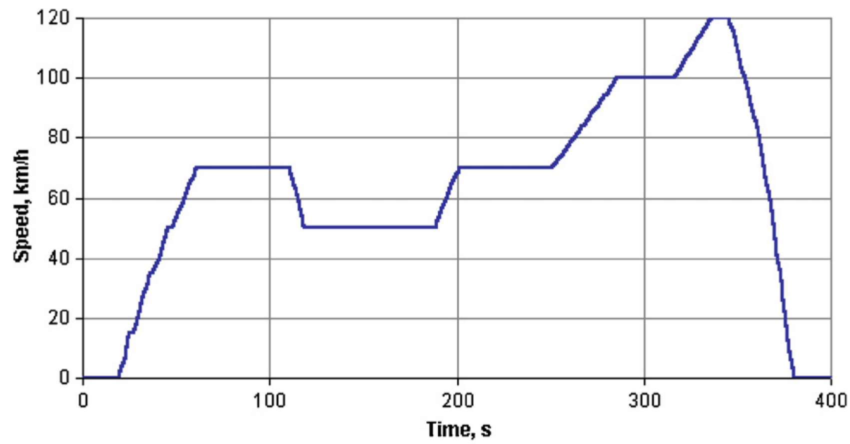

Fig. 13. EUDC cycle.

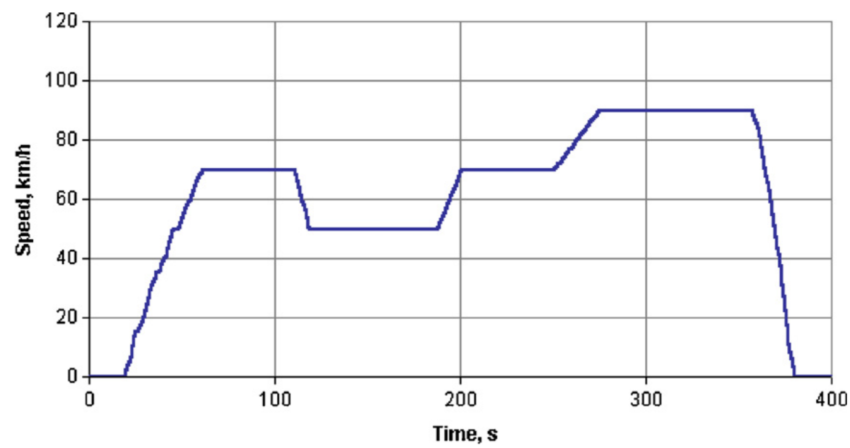

Fig. 14. EUDC cycle for low power vehicles.

driving behavior data analysis [111]. It consists of 16 phases of various durations. Idle periods in the ADC comprise a large proportion of the overall cycle time. The cruising conditions are non-existent and the vigorous changes in traveling speed describe the aggressive way in which passenger's cars are driven in the specified city [112,113]. The profile of ADC presented in Fig. 15 [108].

4.2.2. Edinburgh testing procedure (Scotland)

Edinburgh, is an ancient and historic capital of Scotland and due to its historical nature, the roads are quite narrow. The driving cycle was obtained from data recorded under the actual traffic condition using the car chase technique. The breakdown EDC cycle is presented in Table 9 [114]. The acceleration and deceleration in EDC represent 60% of the total cycle whereas in ECE just third of the total period. The profile of Edinburgh cycle is shown in Fig. 16 [114].

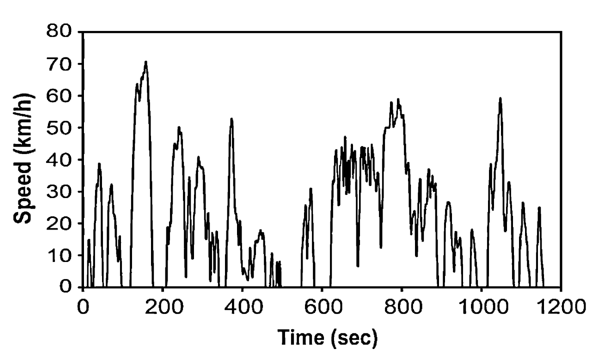

Fig. 15. Athens driving cycle (ADC) test cycle.

4.3. Japan testing procedure

4.3.1. 10 Mode cycle (urban cycle)

The 10 mode cycle was used for emission certification of light-duty vehicles in Japan. It was replaced by the newer 10–15 mode cycle. The 10 mode cycle simulates urban driving conditions with the maximum speed of 40 km/h. The 10 mode cycle or urban cycle is presented in Fig. 17 [103]. The segment of the cycle is presented in Table 10.

Table 9
Edinburgh driving cycle (EDC).

Description	Value
Duration	830 s
Total distance	4.2 km
Average speed	20 km/h

Table 10
10 mode cycle.

Description	Value
Duration	135 s
Total distance	0.664 km (0.41 miles)
Average speed	17.7 km/h (11 miles/h)
Max speed	40 km/h(24.9 miles/h)

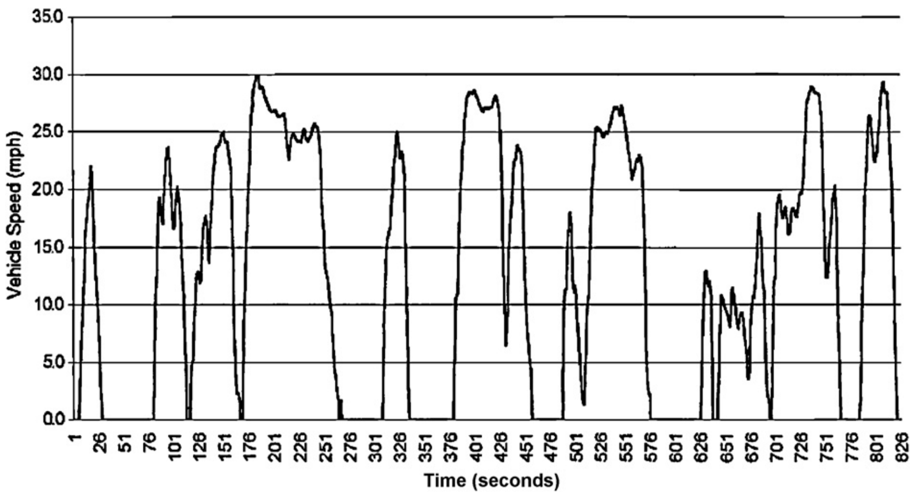

Fig. 16. Edinburgh testing procedure (EDC) test cycle.

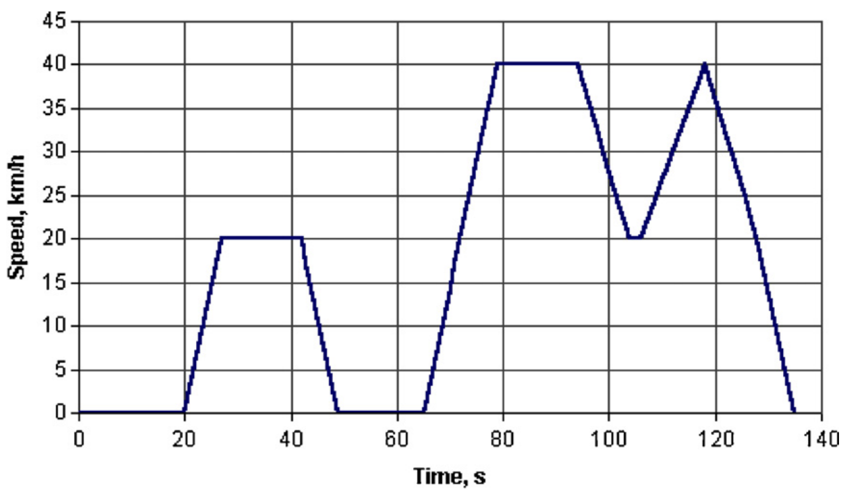

Fig. 17. 10 mode cycle.

The entire cycle begins with a 15 min warm-up period at 40 km/h, followed by six repetitions of the same segment. Emissions are then measured over the last five segments so the emission measurement period represents a route of 3.32 km [103], completed in 675 s. The emissions will be expressed in g/km.

4.3.2. 15 Mode cycle (extra urban cycle)

This cycle represents higher speed driving in an open road environment. It is conducted for decelerations at higher speeds than the 10 mode cycle. The maximum speed is 70 km/h, while the average speed is 33.88 km/h. The complete cycle is presented in Table 11.

4.3.3. 10–15 Mode cycle (combined cycle)

The 10–15 mode cycle is currently for emission certification and fuel economy for light-duty vehicles in Japan. It is derived from the 10 mode cycle by adding another 15-mode segment of a maximum speed of 70 km/h. The emissions are again expressed in g/km [103]. The entire cycle includes a sequence of a 15 min warm-up at 60 km/h, idle test, 5 min warm-up at 60 km/h and one 15-mode segment, followed by three repetitions of 10-mode segments and one 15-mode segment. Emissions are measured over the last four segments ($3 \times$ 10-mode + $1 \times$ 15-mode). The pattern of 10–15 cycles is presented in Fig. 18 and the detail is also tabulated in Table 12 [103].

4.3.4. J08 cycle

Japanese 2005 emission regulation introduced a new JC08 chassis dynamometer test cycle for light-duty vehicles (<3500 kg GVW). The test represents driving in congested city traffic, including idling periods and frequently alternating acceleration and deceleration. Measurement is made twice, with a cold start and with a warm start. The test is used for emission measurement and fuel economy determination, for gasoline and diesel vehicles. The emissions are determined using weighted averages from different cycles, as follows [103,115]:

Table 11
15 mode cycle (extra urban cycle).

Description	Value
Duration	231
Average speed	33.88 km (21.1 miles)
Max speed	70 km/h (43.5 miles/h)

Table 12
10–15 mode cycle (combined cycle).

Description	Value	
	A	*B*
Duration	660 s	892 s
Distance	4.16 km (21.1 miles)	6.34 km (3.94 miles)
Average speed	227 km/h (141.1 miles/h)	25.6 km/h (15.9 miles/h)

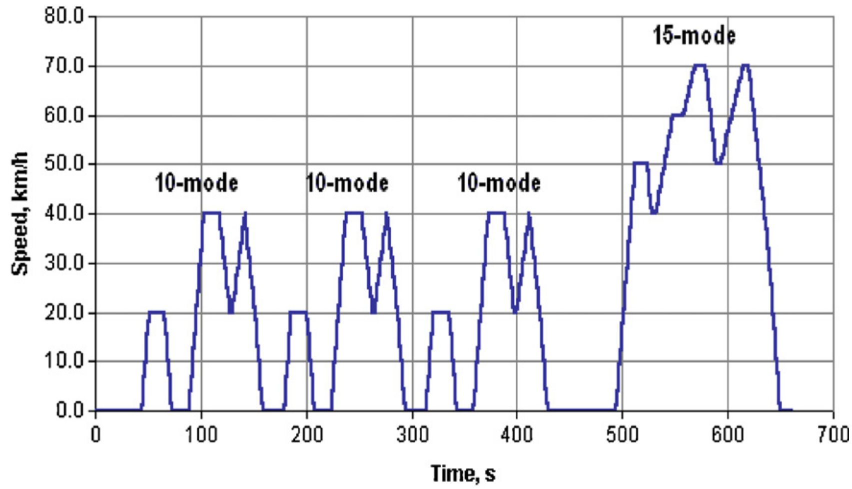

Fig. 18. 10–15 mode cycle.

(i) 2005.10: 12% of 11 mode cold start + 88% of 10–15 mode hot start;
(ii) 2008.10: 25% of JC08 mode cold start + 75% of 10–15 mode hot start;
(iii) 2011.10: 25% of JC08 cold start + 75% of JC08 hot start.

The selected parameters of the JC08 driving schedule are presented in Table 13, and the new Japan driving cycle JC08 effective from the year 2015 is compared with the Japan 10–15 mode cycle in Fig. 20 [103]. The JC08 driving schedule is schematically shown in Fig. 19 [103].

4.4. Australia testing procedure

The value displayed on the fuel consumption label is based on the specific tests conducted by vehicle manufacturers to demonstrate the vehicle's compliance with the Australian Design Rules (ADRs). All vehicles are tested under standard carefully controlled conditions in laboratories. To ensure the quality and consistency of test results, laboratories and their facilities are subject to audit by the Australian Government frequently [116].

The test standard for the current fuel consumption label is specified in the ADR 81/02 fuel consumption labeling for light-vehicles. The label shows the fuel consumption and the CO_2 emission values of the vehicle obtained from the standard dynamometer testing conducted under controlled laboratory conditions. This test is specified in the United Nations Economic Commission for Europe (UN ECE) regulations which sets the procedures for determining fuel consumption and CO_2 emissions for light-vehicles [116].

The 20 min test cycle is split into two phases. Phase 1 is known as the 'urban' cycle that represents conditions found in stop-start traffic and Phase 2 is the 'extra-urban' cycle that involves the vehicle accelerating to a high peak speed. The weighting of the urban and extra urban figures to determine the full combined test result is based on the distance traveled in each part of the cycle. The pattern of ECE Regulation 101 Cycle/NEDC testing procedure is presented in Fig. 21 [116].

Most vehicles have higher fuel consumption on the urban phase of the test cycle, which features a low average speed of 19 km/h, substantial idle period which is 30% and frequent stop and start events. For drivers who spend most of the time in city traffic conditions, this number will provide a more accurate indication of fuel consumption than the combined result. In contrast, the 'extra urban' component has a relatively higher average speed which is 63 km/h and a peak speed at 120 km/h. It is not a typical highway cycle as it does not maintain a relatively constant speed over an extended period of time, but it is more likely to approximate fuel consumption in freeway or highway driving [116].

Table 13
JC08 driving schedule.

Description	Value
Duration	1204 s
Total distance	8.171 km
Average speed	24.4 km/h (34.8 km/h excluding idle)
Max speed	81.6 km/h
Load ratio	29.7%

4.5. New Zealand testing procedure

Most imported vehicles to the New Zealand are either new cars or Japanese used cars. Fuel consumption data for new vehicles is obtained using a European test procedure that is also adopted by Australia and New Zealand and the fuel consumption data for used Japanese vehicles is obtained using a Japanese test procedure. Both procedures involve a standardized test carried out under controlled laboratory conditions where all outside influences, such as driving style, weather, gradient and road condition, are controlled. This allows the test results to be compared to other tests carried out under the same conditions [117]. However, results from Japanese tests are not comparable to the results from European and Australian tests and vice versa.

4.6. Singapore testing procedure

The largest market share for automobile in Singapore is for the Japanese car manufacturers. Some of these Japanese brands are imported from countries other than Japan. However, the testing procedure that is adapted by the Singaporean authority is from ECE Regulation 101 Cycle, which is widely used in European Union. Meanwhile, the continental manufactured cars are not regularly use in Singapore.

4.7. India testing procedure

In India, the European emission test procedure NEDC was adopted with a difference in extra urban driving cycle (EUDC)

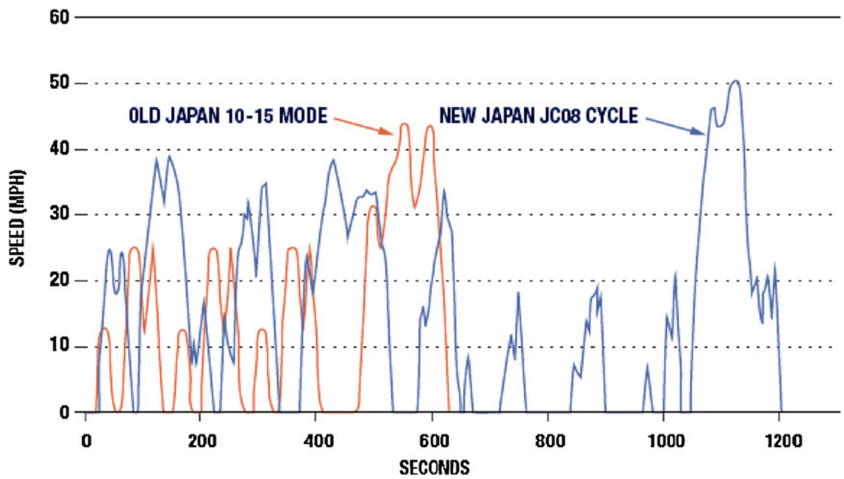

Fig. 20. Japan cycle.

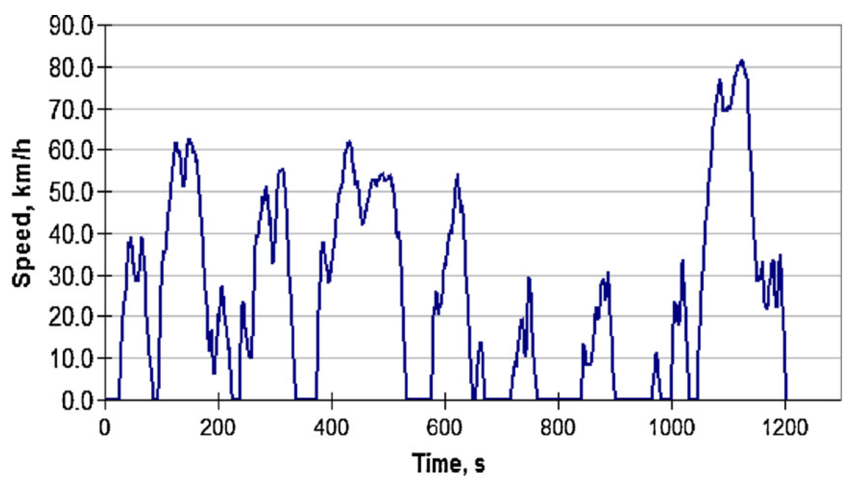

Fig. 19. JC08 test cycle.

part. The maximum speed of 120 km/h was decreased up to 90 km/h in the extra urban driving part of the cycle, which also known as EUDC low powered cycle and the revised cycle is called as the modified Indian driving cycle (MIDC) [118].

4.8. South Korea testing procedure

Today, the automotive industry in South Korea is the fifth largest in the world based on the total number of production and the sixth largest in terms of export volume. The country is today

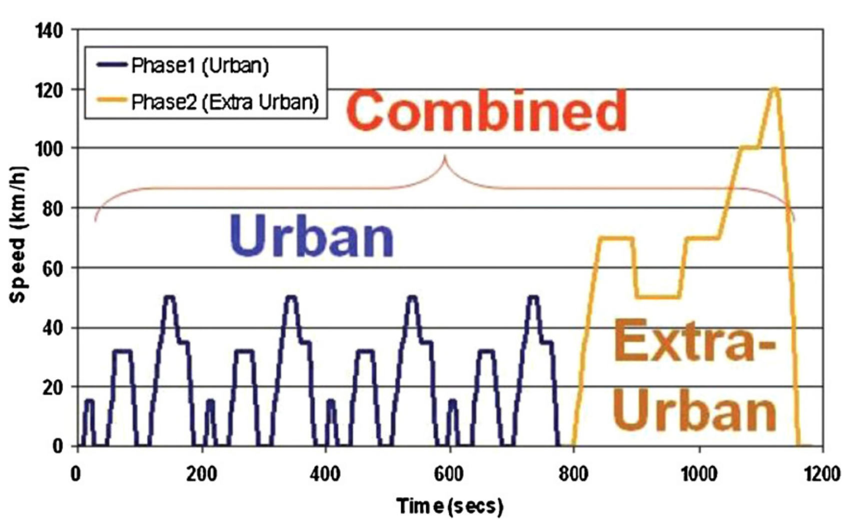

Fig. 21. ECE regulation 101 cycle/NEDC.

Table 14
CECDC driving schedule.

Description	Value
Duration	1862 s
Total distance	9.7 km
Average speed	17.25 km/h
Max speed	49.2 km/h

among the most advanced automobile producing countries in the world [119]. The automobile manufacturers in South Korea are strongly committed to reduce carbon dioxide emissions from automobile. Therefore, the industry is very supportive of any regulation that sets a sound framework, but without discriminating specific technologies or vehicle segments. For the automobile test procedure, the South Korea has adopted only the city driving cycle of the U.S. CAFE for their Fuel economy regulations [118].

4.9. Sweden testing procedure

In Sweden the test procedure cycle consists of two phases, the first phase is for 505 s for the distance of 5.78 km at 41.2 km/h average speed and the second phase is 864 s. The first phase begins with a cold start and the two phases are separated by stopping the engine for 10 min. For this test procedure weighting factors of 0.50 and 0.50 are applied to the first and second phase, respectively [103]. Emissions are expressed in g/mile or g/km.

4.10. Vietnam testing procedure

There is no fuel economy testing procedure currently in Vietnam. The emission testing used in Hanoi previously is European ECE driving cycles. This cycle is used to determine the emission factors of the vehicle [108,113]. Therefore, the representativeness of these emission factors and thus the corresponding emission inventories are uncertain [120]. Vietnam testing procedure for light-duty vehicles is done by Centre for Environmental Monitoring Car Driving Cycle (CECDC). The driving schedule and the CECDC cycle are presented in Table 14 and Fig. 22 [121].

4.11. China testing procedure

The estimation of the fuel economy label in China is based on the testing results conducted in a controlled laboratory using the New European Driving Cycle (NEDC). The NEDC cycle is denoted for Chinese emission standards initially, because China has followed the European's emission standards such as Euro I, Euro II, Euro III. Then this European driving cycle is also use for fuel economy measurements and policy [122]. However, previous studies have pointed out that the European driving cycle is unable to represent the real driving conditions in China [107].

Table 15
BDC driving schedule.

Description	Value
Duration	1160 s
Total distance	5.71 km
Average speed	17.7 km/h
Load ratio	37.7%

4.12. Bangkok testing procedure

In Thailand, the legislative driving test cycle used to evaluate the exhaust gas emission for newly registered vehicles based on the European community (EDC cycle) standard driving cycle [123]. The characteristics of the cycle are apparently different from the real driving condition in Bangkok. The driving cycles (BDC) in Bangkok, which is developed based on the driving patterns, are collected from the real on-road driving under prevailing traffic conditions. The results are presented in Table 15 and Fig. 23 [124].

4.13. Test procedure used globally

The comparison of the majority of test procedures used globally is presented in Table 16 and the overview from countries and

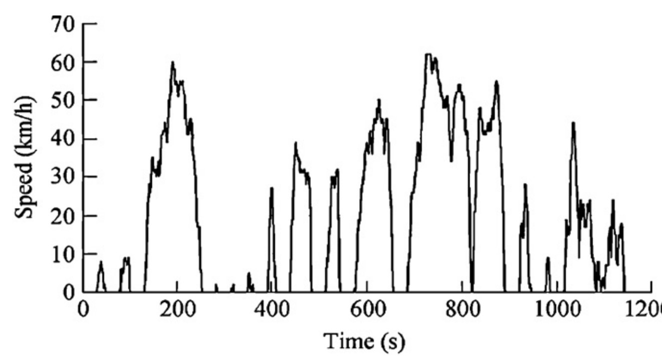

Fig. 23. BDC cycle.

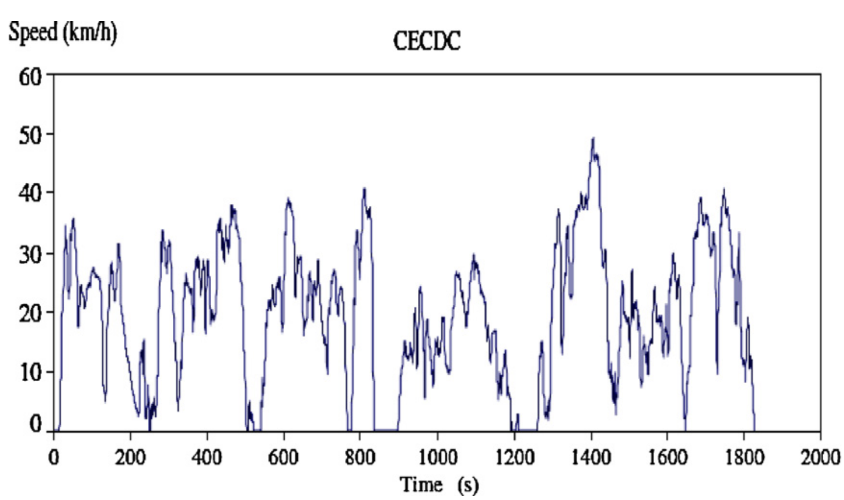

Fig. 22. CECDC cycle.

Table 16
Comparison of selected test procedures mainly used globally.

Country	Cycle	Eng. startup	Length (s)	Distance (mile)	Distance (km)	Av. speed (mph)	Av. speed (km/h)	Idling time	Max speed (mph)	Max speed (km/h)	Max acc. (mph/s)	Max acc. (kmh/s)
USA	EPA city	Cold	1872	11 miles	–	21.2	–	18%	56	–	3.3	–
	EPA highway	Warm	765	10.3 miles	–	48.3	–	None	60	–	3.2	–
	US06	Warm	594	8 miles	–	48.4	–	7%	80	–	8.46	–
	SC03	Warm	594	3.6 miles	–	21.2	–	19%	54.8	–	5.1	–
US CAFE	55% EPA city + 45% EPA high	–	–	–	–	32.4	–	–	60	–	3.3	–
California	UCDS/Unified LA92	–	1435	9.8 miles	–	24.6	–	–	–	–	–	–
New York	EPA NYCC	–	598	1.18 miles	–	7.1	–	–	27.7	–	–	–
EU	ECE/UDC	Cold	780	–	4.052	–	18.7	–	–	50	–	–
	EUDC	Cold	400	–	6.955	–	62.6	–	–	120/90	–	–
	NEDC (ECE + EUDC)	Cold	*1180*	–	*11.01*	–	–	*23.4%*	–	*120*	2.4	3.9
Japan	10–15 mode	–	660	–	4.16	–	22.7	34%	–	70	–	–
	J08	–	1204	–	8.171	–	24.4	None	–	81.6	3.8	6.1

regions that implemented fuel efficiency and GHG standard is tabulated in Table 17 [125,126].

5. Propose test procedure for Malaysia

There are different methods to develop a test procedure to support fuel economy standard, labeling and other related program. The first method is by adopting the exiting test procedure, which considered as a reflection of country's driving cycles. Another method is by developing a real driving cycle that depends on the specified driving condition of the country. During the past decade, several driving cycles have been developed in different countries to represent the real driving condition in that particular country. Some of the testing procedures that adopted by several countries are listed in Table 17. It must be noted that most of the countries adopt the test procedure from U.S., Europe and Japan to support and provide fuel economy standard and label in their country. Eventually, by adopting these methods, the testing procedure is not reflected the real driving condition in the country. However, it is still effective to support the application of fuel economy label as it gives relevant information of fuel consumption and emissions for the consumers. Therefore, the consumer can compare the efficiency of different vehicles.

A real driving cycle is a method that provides the most realistic driving cycle, which will result in an accurate fuel consumption result in that particular place. Therefore, it is necessary to obtain a generally acceptable driving characteristics of the country. One of the methods is to characterize the driving cycle data that are collected from the road. It involved three major components; test route selection, data collections technique and cycle construction methods [120].

Route selection: Representative test routes are important to represent a typical traffic condition in the country. These routes must be determined with the considerations of travel activity patterns (i.e. OD travel patterns) and traffic flow characteristics.

Data collections/on-road testing: The on-road driving tests must be conducted in both weekends and weekdays. The purpose is to collect data reflecting different driving condition based on the routes selected before.

Cycle construction: For this step, driving cycles are developed by considering the driving data records into representative driving cycles. By applying the statistical analysis, the cycle is then modified, and a real world smoothed cycle is presented.

The most obstacle of using this test procedure is its need to retest all imported cars in the Malaysian market both form Japan and European. Instead of using this method to retest the cars, employing the method to support incentive program can be a better choice. Because, even this method uses the real condition of the Malaysian road, there are still other aspects that affect the fuel consumption in real condition. Some these parameters are; the different driving behavior for each person, the engine and tires condition, the lubricant and accessories used, etc.

5.1. Method of selected test procedure

The main concern when choosing to adopt an internationally recognized test procedure should be the applicability of the method for the real conditions. For instance, the speeds used in the testing cycle should not exceed the speed limit set in the particular country. Below is a list of the default speed limits for the Malaysian roads:

(i) Expressways: 110 km/h by default or may be reduced to 80 or 90 km/h at dangerous mountainous stretches, crosswind areas and urban areas with high traffic capacity.
(ii) Federal roads: 90 km/h by default, 60 km/h in town area.

Table 17
Overview from countries and region that implemented fuel efficiency and GHG standard.

Country/region	Type	Measure	Test method	Specific test	Implementation
United States	Fuel	Mpg	U.S. CAFE	55% city + 45% highway	Mandatory
European Union	CO_2	g/km	EU NEDC	ECE + EUDC	Voluntary by now, mandatory by 2012
Japan	Fuel	km/L	Japan 10–15/J08	–	Mandatory
New Zealand	Fuel	L/100-km	EU NEDC+ Japan 10–15	–	Voluntary
China	Fuel	L/100-km	EU NEDC	–	Mandatory
India	Fuel	km/L	EU NEDC	ECE + EUDC low powered	Voluntary
Singapore	Fuel	km/L	EU NEDC	–	Mandatory
California	GHG	g/mile	U.S. CAFE	Unified LA92	Mandatory
Canada	Fuel	L/100-km	U.S. CAFE	–	Voluntary
Australia	Fuel	L/100-km	EU NEDC	ADR 81/02	Voluntary
South Africa	Fuel	km/L	EU NEDC	–	Mandatory
Chile	Fuel	km/L	EU NEDC	–	Voluntary
Brazil	Fuel	km/L	U.S. CAFE	–	Voluntary
Taiwan	Fuel	km/L	U.S. CAFE	EPA city driving only	Mandatory
South Korea	Fuel	km/L	U.S. CAFE	EPA city driving only	Mandatory

(iii) State roads: 90 km/h by default, 60 km/h in town area.

Furthermore, as the market share of Japanese branded motor vehicles outweigh those from the European counterparts and also most of the Malaysian branded cars are manufactured based on the Japanese technology, the Japanese test cycle is more appropriate to be used in the country. The car sales statistic in Malaysia is presented in Fig. 24 [127]. Japanese test cycle is based on the Japan traffic condition. In Japan, most of the roads are toll-free with an exception in expressways and some scenic driving routes. Road conditions tend to be good, although side streets in the cities can be rather narrow. Traffic congestion is a frequent problem in and around urban centers. The typical speed limits are 80–100 km/h on expressways, 40 km/h in urban areas, 30 km/h in side streets and 50–60 km/h elsewhere while the drivers usually exceed the speed limits by about only 10 km/h [128].

In addition to that, Japan and Malaysia have also signed a free trade agreement in December 2005 that commits Malaysia to open its motor vehicle industry to Japanese products over 10 years. By adopting this, it is not necessary to retest the car which will reduce the cost of testing. Therefore, it is recommended that the testing procedure be adopted from the Japan JC08 mode cycle. The Japanese 2005 emission regulation currently introduced a new JC08 mode cycle. The test cycles are performed on a chassis dynamometer where a test vehicle stimulates real on-road driving pattern in a controlled laboratory environment. The test represents driving in congested city traffic, including idling periods and frequently alternating acceleration and deceleration. Measurement is made twice using both cold and warm start. The test is used to determine the emission level and fuel economy for both gasoline and diesel engines.

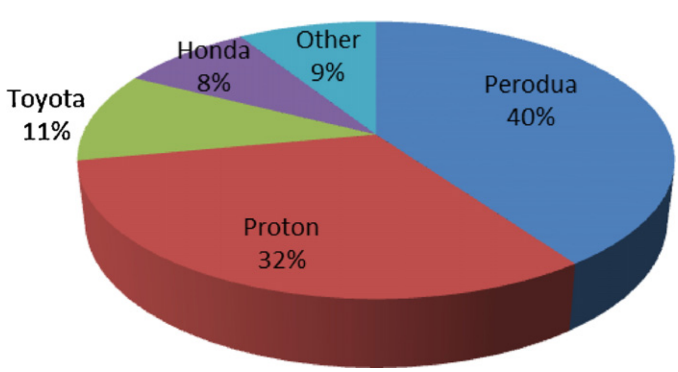

Fig. 24. Malaysia car sales statistic by 2009.

Table 18
Proposed fuel economy test procedure in Malaysia.

Description	Value
Duration	1204 s
Total distance	8.171 km
Average speed	24.4 km/h (34.8 km/h excluding idles)
Maximum speed	81.6 km/h
Load ratio	29.7%

5.2. Suitability of the selected test procedure in Malaysia

Malaysian car manufacturers control more than 70% of passenger car market share in the country followed by Japanese branded with about 20% car sales in 2009. There are two large automobile manufacturers in Malaysia named Proton and Perodua. Since its establishment, Proton makes a partnership with Mitsubishi Corp, which produces Proton Saga that was based on a Mitsubishi Lancer and other Proton models that were mainly based on the Mitsubishi platforms such as Wira and Perdana. Although the partnership of Proton–Mitsubishi was deemed of failure because of the lack of technology transfer, Proton has entered in talks with Mitsubishi once again and the talks are going positive.

The second largest automobile manufacturer is Perodua that was established in 1992. Perodua mainly produces mini cars, which badge engineered from existing Daihatsu designs. It is predicted that the next model of Proton and Perodua car will be based on the Japanese technology and the share of Japanese car in the market will be increased as a free trade agreement between Malaysia and Japan. Because of this reason, using the Japanese JC08 method can be considered as the best approach. The Japanese JC08 driving schedule is shown in Fig. 19 and Table 13. The proposed fuel economy test procedure is tabulated in Table 18.

The test cycles are performed on a chassis dynamometer where the test vehicle stimulates real on-road driving pattern in a controlled laboratory environment. The national motor vehicle manufacturer Proton has already established a Research and Development section where the homologation and testing area are conducted via an existing chassis dynamometer and cold chamber.

6. Conclusions

The test procedure is a foundation that plays a vital role in fuel economy standard, labeling and other related program implementation. The fuel economy standard and label are tools for market transformation. As an emerging industrial country, Malaysia should adopt Japanese JC08 as its fuel economy test procedure for motor vehicles for many beneficial reasons. The adoption of an international recognizes test procedure will secure a place for Malaysian

products in the international market through their accreditation. This approach will diminish the time delays associated with developing a new test procedure. In addition, since there is a trend toward an international agreement about the test procedures for motors and vehicles between Malaysia and Japan, this approach could be recognized as a supporting argument for this purpose. However, this paper is just a beginning toward the introduction of the potential standard and labeling for motors and vehicles in Malaysia. Intensive research involving experts and policy makers in the relevant areas is still required for more advanced results. This piece of work can also act as an example for other countries in the process of selecting fuel economy test procedure.

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